Emerging jellyfish and its significance in local fisheries - a *Periphylla periphylla* story in the Trondheimsfjord

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Abstract
The helmet jellyfish (*Periphylla periphylla*) has become an increasing biological and economic problem for the fishers in many Norwegian fjords over the past few decades. It is known to prey on a variety of planktonic species including small crustaceans such as krill and calanus as well as on fish larvae. Thus, this jellyfish is both a predator and a food competitor of crustaceans and fish species. Recent studies suggest that an increasing abundance of jellyfish may have contributed to a decline in the cod population and productivity in some Norwegian fjords. Abundant local jellyfish populations may cause substantial economic losses for fishers, particularly in small-scale fisheries, due to the reduction in annual fish catches and extra effort required for cleaning and fixing fishing nets.This, in turn, has led to changes in the fishing behavior and well-being of the local fishers. This paper explores the potential ecological and economic consequences of an ongoing *Periphylla periphylla* bloom on the small-scale cod fisheries in the Trondheimsfjord, Norway. Participatory methods of combining interactive workshops and structured questionnaires were used to elicit stakeholders' perceptions and reactions to the emerging jellyfish blooming and their potential adaptation strategies. The study provides valuable insights into the impact of a newly established but permanent jellyfish population on the ecologically and commercially important species in the cod family, and how fishers might adapt to such a continued high local jellyfish presence in their prospects for a future as fishers, and also help policy makers on how to incorporate the experience from this emerging issue into future management and policy process.

Key words: *Periphylla*, cod, Tondheimsfjord, artisanal fishers, stakeholder workshops, questionnaires, perceptions.

Introduction

Over the last few decades, mass occurrences of the helmet (or crown) jellyfish *Periphylla periphylla,* hereafter called *Periphylla*, have been reported in several fjords along the Norwegian coast from Lurefjorden on the south-west coast to Saltenfjorden in Bodø in the north (Fosså, 1992; Youngbluth & Båmstedt, 2001; Sneli, 1984; Hetland, 2008; Bozman, 2010, Tiller *et al*., 2016). *Periphylla* is a long-lived deep-sea predatory scyphozoan jellyfish belonging to the order Coronatae of the phylum Cnidaria

(Jarms, 1997). It is found in all world oceans including the Arctic and Antarctic. Occasionally it has been caught at depths of 7 000 meters, and is perfectly adapted to a dark environment (Kramp, 1959). It is holopelagic and has a direct development from eggs to adults. The fertilized eggs are dispersed into the open water where they develop into medusa through 14 stages (Jarms *et al.,* 1999). *Periphylla* appears to breed throughout the year, with a possible peak in autumn and early winter in the northernmost infested fjords, including the Trondheimsfjord (Bozman, 2010; Borgersen, 2013). *Periphylla* prey on a variety of planktonic organisms including larvae and juveniles of its foodweb rival species like codfishes, and on small crustaceans like krill and calanus spp (Kaartvedt *et al.,* 2007 & 2011; Tiller *et al*., 2015). Because other scyphozoan jellyfish are known to prey on fish eggs (Purcell *et al.,* 1994; Barz & Hirche, 2007), it has been suggested that *Periphylla* may become a potential predator on these as well.

Equipped with some of the largest stinging cells amongst jellyfish species (Jarms *et al.,* 2002), this predatory jellyfish appears as a serious threat to the juvenile stages of important local fish stocks in Norwegian fjords, like those of the various codfishes, herring and sprat. The threat is not only as a competitor for the same food sources (Hansson *et al*., 2005), but also as a predator of their competitor's fragile larvae and juveniles (Zeman *et al.,* 2016; Eriksen *et al*., 2012). When reaching a certain level of population biomass in a local ecosystem, the jellyfish may outcompete its rival species and potentially become the top predator in the ecosystem, a process named the "*jellyfish spiral*" (Uye, 2008), from which its rival species find it difficult to recover, and might even disappear.

The causes of jellyfish blooms have been suggested to be a combination of anthropogenic stressors and natural changes in ecological processes, including eutrophication, overfishing, introduction of non-indigenous, species and climate change (e.g., Lynam *et al.,* 2005; Hay, 2006; Purcell *et al.,* 2007; Richardson *et al.,* 2009; Purcell, 2012; Roux *et al.,* 2013). In some cases, overfishing may remove predators of jellyfish (Condon *et al.,* 2012; Milisenda *et al.,* 2014), further complicating the ability to survive and maintain healthy populations for rival fish species already threatened by their gelatinous competitors (Robinson *et al.,* 2014). Global climate change has caused the ocean to warm up rather unpredictably over the years (IPCC 2014). Jellyfish, in contrast to boreal fish species that are negatively affected, have enjoyed the warm climate (Chiaverano *et al.,* 2013; Robinson *et al.,* 2014), and thrived in environments which they previously did not inhabit, exemplified by the *Periphylla* infestations along the Norwegian coastline and fjords (Tiller *et al*., 2016). Increased water temperatures and pollution have resulted in richer nutrient levels that may enhance plankton growth and change the ocean productivity. When the waters of the Norwegian fjords are darkened owing to climate change and eutrophication and thus light attenuation is increased, jellyfish have a unique advantage over fish by being non-visual hunters. Fish species rely on eyesight for hunting and thus struggle to find prey in dark environment, while the jellyfish find prey by physical contact with their tentacles (Youngbluth & Båmstedt, 2001; Sørnes *et al.,* 2007; Aksnes *et al.,* 2009). It is evident that jellyfish and forage fish display replacement cycles on intradecadal time scales (Robinson *et al*., 2014).

The rapid increase in the abundance of *Periphylla* has become an increasing ecological and economical problem for the traditional fisheries in many Norwegian fjords (Tiller *et al*., 2016). With dense populations consistently throughout the year on traditional fishing grounds, *Periphylla* clearly poses negative effects on fishing activities, especially on the traditional and small-scale fisheries. This is certainly the case for the Trondheimsfjord, the focus of this study. Small-scale fishers use traditional net gear in the coastal areas and fjords on a daily basis. It is mainly for subsistence and is the common source of livelihood (Jentoft and Johnsen, 2015). Recently, fishers have reported that *Periphylla* have replaced the commercial fishing stocks in some fishing areas, which leads them to relocate fishing

grounds, resulting in longer working hours, increased fishing costs and decreased income due to loss of traditional fishing grounds. Jellyfish venom is highly toxic to fish species (Helmholz *et al.,* 2010). Dependent upon the degree of physical contact with the tentacles, it can cause severe stress, blindness and even death to the fish (Båmstedt *et al.,* 1998). Whenever trapped together with *Periphylla* in the fishing nets or trawls, the fish is severely stung by the toxic tentacles of the jellies and the commercial value of the fish is decreased. Furthermore, when *Periphylla* die and sink to the bottom, the decaying corpses sap oxygen from the local environment and change nutrient compositions leading to reduced amounts of available oxygen and irregularities in nutrient cycles for the bottom species inhabiting the area (Titelman *et al.*, 2006; West *et al.,* 2009). These effects on the ecosystem and environment are observed, but difficult to quantify (Nakar, 2011). The economic pressures might, in a worst case scenario, force fishers to change profession or even end up to be unemployed depending on sources, e.g., social support, and thus imposing potential costs on the society.

Periphylla and fishing in the Trondheimsfjord

The Trondheimsfjord is the third longest and the seventh deepest fjord in Norway. The fjord is 126 km long, 630 m deep, and the total volume is about 235 km^3. The fjord is located in the west-central part of Norway in Trøndelag County, stretching from Ørland municipality in the west to the Steinkjer municipality in the north. The fjord is naturally divided in three basins (largest and mean depths in parentheses); Outerfjorden (600m/212m), Midtfjorden (400m/130m) and Innerfjorden (240m/86m), separated by shallower sills at Agdenes, Tautra and Skarnsundet. Innerfjorden includes Beitstadfjorden and a narrow side-arm called Verran and including two shallower basins called Verrasundet (100m) around station 2 and Verrabotn (65m) around station 1 (Fig.1). Six large rivers discharge fresh water into the fjord from land areas on the east and south sides of the fjord. These discharges set up a strong estuarine circulation transporting the water masses from these rivers to the inner part of the fjord and then as a main outgoing water transport along the northwestern side of the fjord. The tides are semi-diurnal with an average amplitude of 1.8 m.

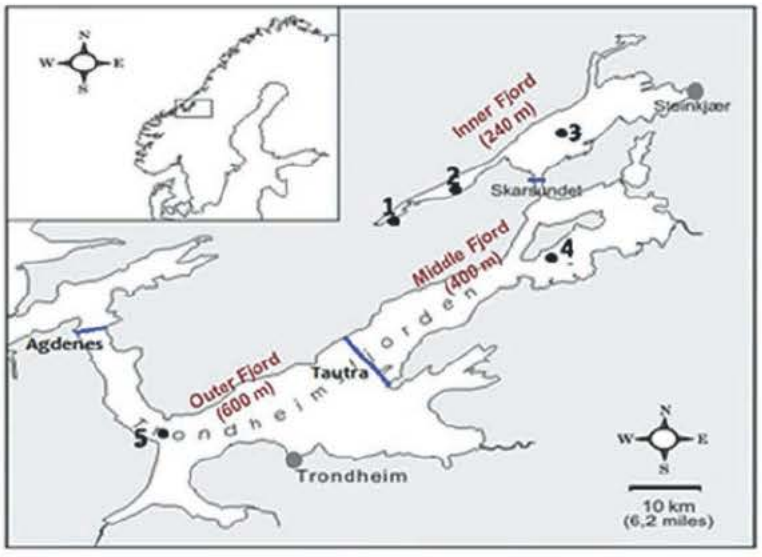

Figure 1. The Trondheimsfjord with the three basins marked together with five hydrographic stations. The three basins are outer fjord, middle fjord ans inner fjord, divides by three sills at Agdenes, Tautra and Skarnsundet as indicated by solid blue bars.

The hydrographical conditions (estuarine circulation) of the fjord are heavily influenced by the sills, basins depths and the presence of several large rivers which empty in the inner parts of the fjord, *e.g.* by

causing large spring floods and substantial vertical density stratification-differences between basins. Annual inflows of heavier Norwegian Coastal-current water and Atlantic water replace the bottom water at least once a year. The depths and distances to the river estuaries along the fjord influence a variety of ecosystems. The fjord lies in a boreal-arctic transition zone and is a relatively self-sustained and fully functional ecosystem. Over 100 species of fish use this fjord as their vital habitat, including a number of important marine species and resources such as cod and herring. The local cod stock has traditionally been the keystone species in the ecosystem and has supported local fishers for their livelihood for centuries (Mork *et al*. 1982, Mork *et al*., 1985).

Periphylla has established a self-recruiting stock in the Middle and Inner Trondheimsfjord since 1999, especially in the Beitstadfjord basin where the *Periphylla* bloom has been more extensive than in other parts of the fjord. It first became a notable nuisance for local fishers in the Trondheimsfjord in the early 2000s. The infestation of the fjord and the establishment of a large jelly biomass took about 10 - 12 years (Borgersen, 2013). The current jelly population is estimated at > 60 000 metric tons in the Beitstadfjord alone, where also the assumed *mother population* is located (Hetland, 2008; Jøssang, 2015). The jelly population is effectively recruiting itself and now thriving. For example, the biomass estimates in 2015 were more than five times higher than those in 2007 (63 998 tons *vs*. 11 291 tons respectively, Jøssang, 2015). Unlike most fish species, *Periphylla* have high tolerance to environmental changes such as increased temperatures, salinity variations, reduced oxygen saturation and increased light attenuation. These are environments to which most fish species struggle to adapt, and may lead them to being gradually outcompeted in the Trondheimsfjord by the jelly over the last decade or so (Hetland, 2008; Solheim, 2012; Borgersen, 2013; Jøssang, 2015). Fig.2 shows the different sizes of *Periphylla* caught in one bottom trawl hawl by R/V "Gunnerus" of NTNU in the inner Trondheimsfjord in 2014. Such size series and an overall large over-representation of small individuals in the trawl catches indicate a continuous successful recruitment to the standing *Periphylla* population in the inner Trondheimsfjord during the last decades.

Figure 2. Common *Periphylla* size distribution in routine bottom trawl catches from the inner Trondheimsfjord (Photo by Jarle Mork).

The jellyfish has caused a series of problems to the local ecosystems and marine resources that coastal fishers in the areas depend on for their livelihood. These artisanal fishers are very vulnerable to *Periphylla* infestations. Those fishers who use Beitstadfjord as their major fishing grounds are affected considerably by *Periphylla*. However, the level of impacts depends on the fishing gears being used, the fishing grounds and seasons fished, and the abundance of jellyfish in the ecosystem. The jellyfish can clog the nets and engines of fishing vessels. Fishers are stung while removing the jellyfish from the nets

as well as bearing the subsequent cost of cleaning the nets. Harvested fish are likely damaged, resulting in reduced value of the catch. However, the economic losses and social impact are difficult to be quantified due to lack of data and level of impacts. Currently, the most important fish species for the coastal fishers in the Trondheimsfjord are codfish species including cod, pollock and saithe. Emerging species like pollock and crab have also gradually become important to local fishers as an income supplement in light of declining cod stocks possibly due to the jellyfish infestation combined with other factors such as climate change and dynamics of fish market. The artisanal fishers have witnessed the changes in the fisheries resources and fishing conditions over time. The main fishing season takes place in spring from March to May when the fish are residing in the coastal areas for spawning. Local artisanal fishers use 30 - 35 feet coastal fishing vessels with conventional and low-tech gears such as gillnets to harvest these fish species. They fish in the areas close to their homes due to strict regulations on landing sites and their daily possibility to travel. They depend on these fisheries as their livelihood and a way of lifestyle.

Materials and data

Data and information were collected through the combination of field surveys, interactive stakeholder workshops and structured questionnaires with fishers. The stakeholders who participated in the workshops and questionnaires are full-time/part-time artisanal or small-scale commercial fishers who have been fishing in the Trondheimsfjord, especially in the inner fjord for over a decade. Fishing has been the source of their income to support their livelihood, also been the way of their lifestyle for generations, and they are not willing to change. These fishers have extensive knowledge about the sea and marine resources, and have encountered *Periphylla* in their catches, and observed *Periphylla* starting to bloom over the years.

Field surveys

During decade-long scientific surveys and data collections in the Trondheimsfjord, data have been collected by Trondhjem Biological Station (TBS) for *Periphylla* and cod in spring and autumn samples. Five sampling stations covering the relevant fjord basins (Fig. 1) were selected for field surveys which covered both spring and fall hydrographical and planktonic conditions. A specially designed Light Weight Video Trawl (LWVPP) performing U-dives enabled size measurements and counting of individual *Periphylla* (see details in Jøssang, 2015). On each survey, at least two repeated hauls were made at each location. Trawling speeds and times were recorded, thus enabling calculations of filtered water volume and catch per unit effort (CPUE) of *Periphylla* and cod. Parallel bottom shrimp-trawl catches on the same locations were manually counted for *Periphylla* and fish species and their numbers. Based on information from these sources, the respective biomasses of *Periphylla* and the various fish species were calculated.

Participatory workshops.

Two interactive and participatory workshops were organized with local fishers in both Sør- and Nord-Trøndelag to collect qualitative information on the fishers' perceptions about *Periphylla*, including their opinion on *Periphylla* occurrence in the fjord and their adaptive capacity to *Periphylla* infestations. The first workshop was held in Trondheim located in Sør-Trøndelag with four independent fishers who live in the city of Trondheim. They were commercial fishers and not affected by *Periphylla* themselves, but they were aware the presence of *Periphylla* and heard that other fishers in the fjord were affected by *Periphylla*. The second workshop was held in Steinkjer, a city in Nord- Trøndelag. Seven local fishers were invited and attended the workshop. They were active fishers in the fjord either full-time or part-time and they had encountered *Periphylla* on several occasions and therefore had personal experiences

and views on the matter. The detailed approaches from these workshops can be found in Tiller *et al.* (2014 & 2015).

Structured questionnaire survey.

Following the workshops, a structured questionnaire survey was designed and conducted among the small-scale artisanal fishers in the inner Trondheimsfjord for cod fishing. This survey was to explicitly examine the potential impacts of jellyfish on their fishing activities and possible adaptation strategies. The fishers surveyed are those who have encountered *Periphylla* and were affected to some extent occasionally. The questionnaire was divided into a few sections, including basic fishing information like fishing area, gear and season, economic components like catch and catch composition, price and cost, their views on *Periphylla* effects and social-demographic characteristics of fishers. The questionnaire was administrated by mail to all the fishers, and phone calls were followed up after a couple of weeks later. Half of which replied with relatively complete answers resulting in a response rate of 50%. Both qualitative and quantitative data were collected.

Results

The results from the field surveys clearly indicated that there is a negative relationship between the abundance of *Periphylla* and cod stock size (Fig. 3). The catch per unit effort (CPUE) of *Periphylla* has sharply increased (dotted red line) while the CPUE of cod has drastically fallen down (solid dark blue line) for the same period. This divergent development suggests that *Periphylla* may have had negative impacts on cod, and certainly on the fishing patterns of the local fishers. It should be noted that the decreases in the catch of cod is due to sample size, location and time of fishing, thus, it didn't imply that cod stock is on the brink of extinction. However, the sharp drop in the spring sample of 2013 was contributed by a documented mass death of *Periphylla*.

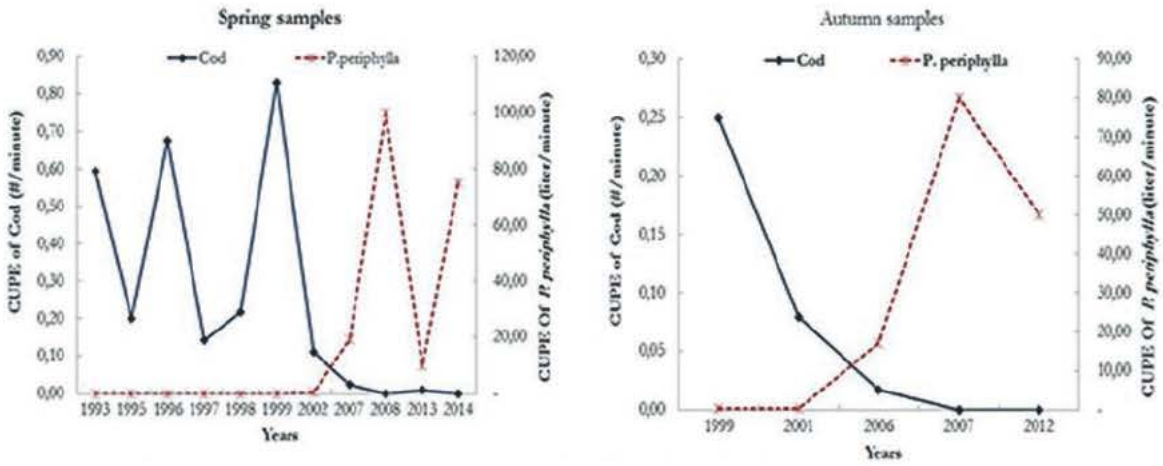

Figure 3. The catch per unit efforts (CPUE) of Cod vs. Periphylla.

In order to compare the data from the surveys, aggregated data from the National statistics for Trøndelag area (including Sør- and Nord-Trøndelag) and data from the questionnaire (e.g., fisher's logbook) were used to illustrate the changes in fisheries resources over the last decade. The catch composition of fishers' catch has changed substantially in the last decade (Fig. 4). The results indicated that cod and saithe are still the dominant species in terms of catch and value, although overall the cod catch has shown a rapid decline in the last few years (Fig. 4). For example, the catch of cod has halved from over 60% in 2000 to about 30% in 2012 while the catch of saithe has increased from 20% to 50% at the same period. Hake and Pollack have also shown increasing trend since they receive better price in the market

due to increasing demand. However, according to the responses to the questionnaires in the current study cod is still the fishers' favourite species to catch although the price of cod has gradually declined.

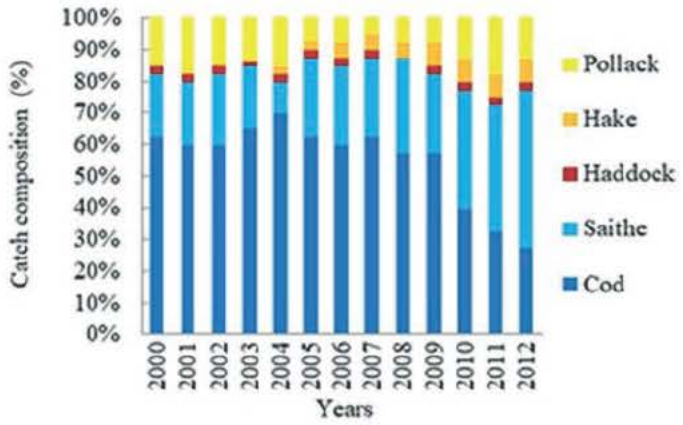

Figure 4. The catch composition from fisher's logbook.

The results from the two workshops are synthesized in Figure 5. The fishers at the workshop in the North Trøndelag had encountered *Periphylla* during their fishing occasionally while the fishers in Trondheim in the South Trøndelag just heard about *Periphylla* but had no personal experience with it. It, however, turns out that the both group fishers have shown the same concern about the ultimate effects of *Periphylla*, which is the decreased or lower income. Which is not surprising as fishing is the main source of their income. They also expressed their concerns about the direct effects of *Periphylla* on: 1) fish larvae mortality due to predation, 2) adult fish mortality due to stinging danger and predation, and 3) damaged catch by direct contact with fish in the net. Additional factors regarding *Periphylla* were also very similar for both groups of fishers.

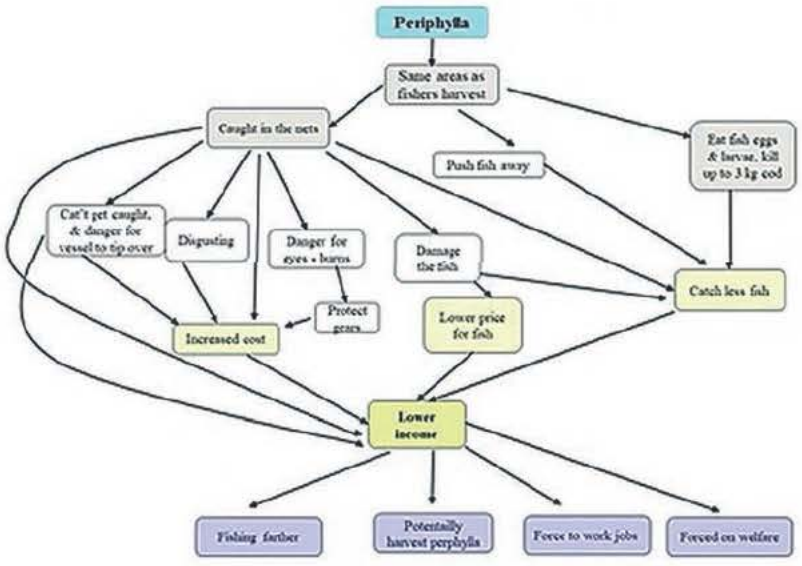

Figure 5. Traced tree summing up fishers' perception about *Periphylla*.

The results from the questionnaire revealed similar claims as those in the workshops. Overall effects of *Periphylla* on fishing are larger, in the magnitude of more than 3 on average with a scale 0 representing

no effects and a scale of 5 strongest effects. The impacts in the Beitstadfjord is stronger than in other parts of the fjord (Fig. 6) as expected because the Beitstadfjord is where the 'mother population' comes from. The effects, however, vary in terms of fishing area, fishing gear and time used, and working hours for cleaning nets. Of which, fishing areas and fishing time have stronger effects than fishing gears and working hours for cleaning nets. The fishers further indicated that their total income from cod fishing was reduced over the last decade, but *Periphylla* is not the primary cause although the catch of cod was reduced. The fishers reported that the main factor causing income loss is, however, the market price of cod and increasing fishing costs of fuel and materials, especially for the fishers who are commercial fishers and have not encountered jellyfish yet. The data from the statistics clearly showed that the price of cod has declined in the last several years. Nevertheless, it is believed that the increasing fishing cost is partially due to *Periphylla* because fishers need to go farther out their fishing zones and spend longer hours in sea, and require more hours to clean the clogged nets and repair torn nets. This in turn could partially explain the declining CPUE for cod and the increasing CPUE for *Periphylla* (illustrated in Figure 3).

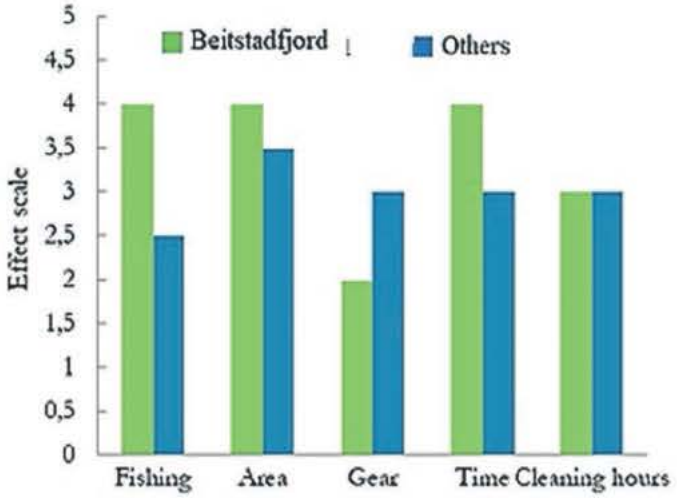

Figure 6. The effects of *Periphylla* on small-scale cod fishing.

To continue fishing in a jellyfish infested fjord, the fishers have to mitigate and/or adapt the situation while minimize the negative impacts. From the workshops and surveys, the fishers indicated some alternatives. For instance, if the infestation is very severe, the fishers may leave the jelly affected fishing areas to go somewhere else if they have access to them. If they have to stay at the affected fishing ground, they then may have to do something else to compensate the lost income, like farming instead fishing. Some of them further mentioned that they have thought to sell their fishing vessels and permits if *Periphylla* continues to be the problem and alternatives become less available. They stressed that if *Periphylla* can be explored and used for commercial values, they would be willing to harvest them. This is how fishers have gradually adapted to the situation if they cannot mitigate the jellyfish problem.

Discussion

Over the last decade, the ecological structure and abundance of species in the fjord have been altered due to a combination of factors including climate change, darkening waters, pollution and jellyfish infestation, increased fishing pressure and market demand. These combined factors have led to changes in fishing behavior and patterns. *Periphylla* has negative effects on fishing activities and fisheries, and has the potential to profoundly affect the marine ecosystem in term of taking over as a top predator and competitor, not only in Trondheimsfjord, but also in other Norwegian coastal areas (Tiller *et al.*, 2016).

This paper demonstrates that the jellyfish proliferation in the Trondheimsfjord has become a growing concern to the small-scale fishers.
As species distributions change in response to climate change and other environmental shifts, small-scale fishers are more vulnerable, and may be less able to adapt because of limited mobility and fishing capacity. Traditional area-based access rights institutions will become strained by the loss or relocation of local marine resources. However, while some fishers will see the disappearance of their target fish species, others could see an opportunity in the landings of species of high commercial value. The fishers did, however, see some hope in the possibility in harvesting *Periphylla* for income generation, given that certain conditions were met.

The direct loss resulting from fishing these species is not detrimental to the fishers' livelihood at the moment. Overall fishers have maintained their income level because the income loss from cod fishing has been compensated by the income from other activities like increasing opportunities for emerging species, like crab and pollack or farming, as well as financial support from the government (thanks for the good welfare system in Norway). For instance, some fishers indicated that only half of their incomes came from fishing and the other half from other activities. Since fishing is their lifestyle, they prefer fishing as long as they can sustain their livelihood. However, the fishers in general perceived the future fishing in the Trondheimsfjord as not very promising due to the reduced income from fishing. They believe that policy and management can help improve their fishing situation, but they are against new fishing regulations that may potentially restrict their fishing activities such as fishing areas and seasons. These contradictory claims show that the fishers do not totally believe that policy and management can change the jellyfish situation, but they do need financial support for maintaining their fishing activities.

* this chapter is to be cited as :

Liu Y., 2, Gjelsvik Tiller R., Mork J. and Borgersen Å.L. 2018.Emerging jellyfish and its significance in local fisheries - a *Periphylla periphylla* story in the Trondheimsfjord. pp. 171 – 179 In CIESM Monograph 50 [F Briand Ed.] Engaging marine scientists and fishers to share knowledge and perceptions – Early lessons. CIESM Publisher, Monaco and Paris, 218 p.